CHAPTER 2 - METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE IN ROOM FIRE WITH FORCED VENTILATION

COMPARTMENT WITH THERMALLY THICK BOUNDARIES

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	8.00	ft	2.44 m
Compartment Length (l_c)	8.00	ft	2.44 m
Compartment Height (h_c)	6.00	ft	1.83 m
Interior Lining Thickness (δ)	9.00	in	0.2286 m

For thermally thick case the interior lining thickness should be greater than 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.20	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.16	$(kW/m^2\text{-}K)^2\text{-sec}$
Interior Lining Thermal Conductivity (k)	0.00053	kW/m-K
Interior Lining Specific Heat (c)	1.25	kJ/kg-K
Interior Lining Density (ρ)	240	kg/m^3

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kpc $(kW/m^2\text{-}K)^2\text{-sec}$	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002 Page 270.

Select Material
Fiber Insulation Board
Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	400.00	cfm	0.189 m^3/sec 0.227 kg/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	500.00	kW

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-140.

$$\Delta T_g/T_a = 0.63(Q/mc_pT_a)^{0.72}(h_kA_T/mc_p)^{-0.36}$$

Where
$\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_p = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation **Thermally Thick Material**

$t_p =$ $(\rho c_p/k)(\delta/2)^2$

Where ρ = interior construction density (kg/m^3)
c_p = interior construction heat capacity (kJ/kg-K)
k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)

$t_p =$ **7394.99** sec

Heat Transfer Coefficient Calculation

$h_k =$ $\sqrt{(k\rho c/t)}$ for $t < t_p$

Where $k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

Area of Compartment Enclosing Surface Boundaries

$A_T =$ $2\ (w_c \times l_c) + 2\ (h_c \times w_c) + 2\ (h_c \times l_c)$

$A_T =$ **29.73** m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

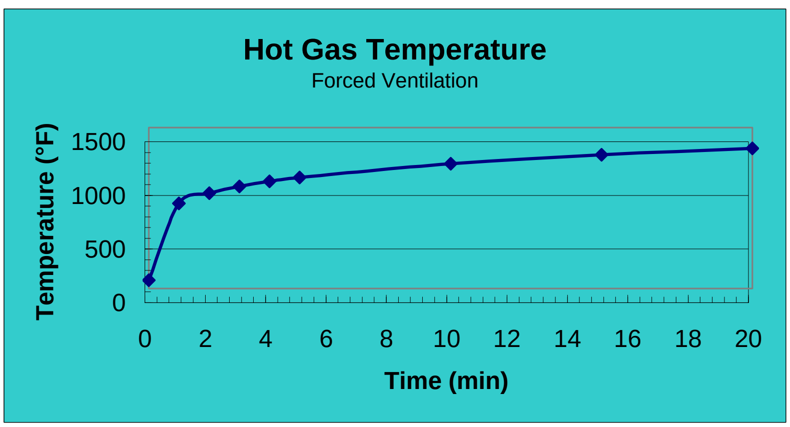
$\Delta T_g/T_a = 0.63(Q/mc_pT_0)^{0.72}(h_kA_T/mc_p)^{-0.36}$

$\Delta T_g =$ $T_g - T_a$

$T_g =$ $\Delta T_g + T_a$

RESULTS

Time after Ignition (t)		h_k	DT_g/T_0	DT_g	T_g	T_g	T_g
(min)	(s)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	1.34	398.58	696.58	423.58	794.44
2	120	0.04	1.52	451.54	749.54	476.54	889.77
3	180	0.03	1.63	485.73	783.73	510.73	951.31
4	240	0.03	1.72	511.54	809.54	536.54	997.78
5	300	0.02	1.79	532.51	830.51	557.51	1035.51
10	600	0.02	2.02	603.27	901.27	628.27	1162.89
15	900	0.01	2.18	648.95	946.95	673.95	1245.10
20	1200	0.01	2.29	683.43	981.43	708.43	1307.18



NOTE

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CHAPTER 2 - METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE IN ROOM FIRE WITH FORCED VENTILATION

COMPARTMENT WITH THERMALLY THICK BOUNDARIES

The following calculations estimate the hot gas layer temperature in enclosure fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
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INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	40.00	ft	12.19 m
Compartment Length (l_c)	40.00	ft	12.19 m
Compartment Height (h_c)	12.00	ft	3.66 m
Interior Lining Thickness (δ)	2.00	in	0.0508 m

For thermally thick case the interior lining thickness should be greater than 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.20	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia (kρc)	0.001	(kW/m^2-K)^2-sec
Interior Lining Thermal Conductivity (k)	0.000034	kW/m-K
Interior Lining Specific Heat (c)	1.5	kJ/kg-K
Interior Lining Density (ρ)	20	kg/m^3

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kρc (kW/m^2-K)^2-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 270.

Select Material
Expanded Polystyrene
Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	6000.00	cfm	2.832 m^3/sec 3.398 kg/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	1500.00	kW

METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-178.

Heat Transfer Coefficient Calculation

$h_k = 0.4\sqrt{(k\rho c / t)}$ for $t < t_p$

Where kρc = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)

$h_k =$ 0.002 kW/m^2-K

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

$A_T =$ **475.66** m^2

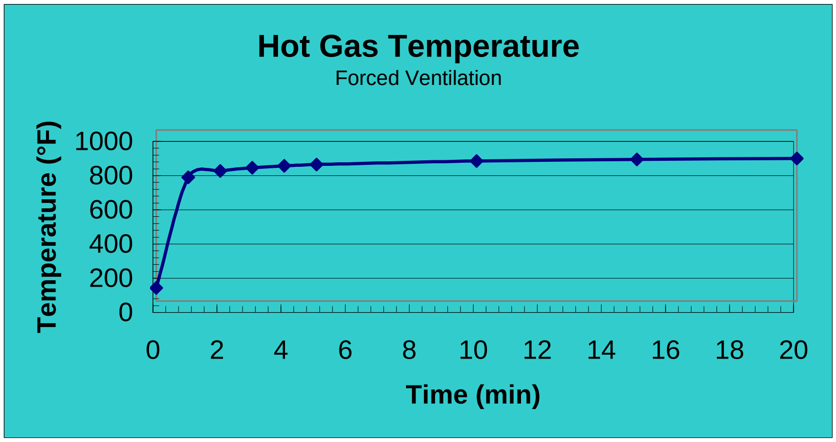
Compartment Hot Gas Layer Temperature With Forced Ventilation

$\Delta T_g = Q / (m\, c_p + h_k\, A_T)$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_p = specific heat of air (kJ/Kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Results:

Time after ignition (t)		h_k	DT_g	T_g	T_g	T_g
(min)	(s)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.00	359.30	657.30	384.30	723.74
2	120	0.00	380.01	678.01	405.01	761.02
3	180	0.00	389.97	687.97	414.97	778.94
4	240	0.00	396.15	694.15	421.15	790.08
5	300	0.00	400.49	698.49	425.49	797.88
10	600	0.00	411.67	709.67	436.67	818.01
15	900	0.00	416.83	714.83	441.83	827.30
20	1200	0.00	419.97	717.97	444.97	832.94



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CHAPTER 2 - METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE IN ROOM FIRE WITH DOOR CLOSED

The following calculations estimate the hot gas layer temperature in enclosure fire with door closed.
This method assume that compartment has sufficient leaks to prevent pressure buildup, but the leakages are ignored.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	16.40	ft	5.00
Compartment Length (l_c)	16.40	ft	5.00
Compartment Height (h_c)	13.12	ft	4.00
Interior Lining Thickness (δ)	1.00	in	0.0254

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	82.00	°F	27.78
			300.78
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.20	kg/m^3	
Volume of the Compartment (V)	3528.76	ft^3	99.92
Mass of the Gas in the Compartment ($m = V \times \rho_a$)	119.91	kg	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia (kρc)	0.098	$(kW/m^2\text{-}K)^2\text{-sec}$
Interior Lining Thermal Conductivity (k)	0.00013	kW/m-K
Interior Lining Specific Heat (c)	1.12	kJ/kg-K
Interior Lining Density (ρ)	700	kg/m^3

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kρc $(kW/m^2\text{-}K)^2\text{-sec}$	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 270.

Select Mat
Calcium Silicate Boar
Scroll to de
Click on se

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	100.00	kW
Time after Ignition	120	sec

METHOD OF BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-180.

$$\Delta T_g = (2\,K_2 / K_1^2)\,(K_1 vt - 1 + e^{(-K1\,vt)})$$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Parameter $K_1 = 2(0.4 \sqrt{k\rho c})/mc_p$
Parameter $K_2 = Q / m\, c_p$
$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec
m = mass of gas in the compartment (kg)
c_p = specific heat of air (kJ/kg-K)
Q = heat release rate of the fire (kW)
t = exposure time (sec)

Calculation for Parameter K_1

K_1 = $2(0.4 \sqrt{k\rho c})/mc_p$

K_1 = **0.0021** $kW/m^2\text{-}K$

Calculation for Parameter K_2

K_2 = $Q / m\, c_p$

K_2 = **0.834**

Compartment Hot Gas Layer Temperature, Compartment Door Closed

$\Delta T_g = (2 K_2 / K_1^2)(K_1 \sqrt{t} - 1 + e^{(-K_1 \sqrt{t})})$

$\Delta T_g = T_g - T_a$ = **99.32**

T_g = **400.10** K

T_g =	**127.10 °C**	**260.77231 °F**	**ANSWER**

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CHAPTER 2 - METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN ROOM FIRE WITH NATURAL VENTILATION
COMPARTMENT WITH THERMALLY THIN BOUNDARIES

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	15.00	ft	4.572 m
Compartment Length (l_c)	16.00	ft	4.8768 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	6.50	ft	1.981 m
Vent Height (h_v)	5.60	ft	1.707 m
Top of Vent from Floor (V_T)	8.00	ft	2.438 m
Interior Lining Thickness (δ)	0.80	in	0.02032 m

For thermally thin case the interior lining thickness should be less than or equal to 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.20	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia (kpc)	0.001	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.000034	kW/m-K
Interior Lining Specific Heat (c)	1.5	kJ/kg-K
Interior Lining Density (ρ)	20	kg/m^3

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kpc $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
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Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 270.

Select Material
Expanded Polystyrene
Scroll to desired material then
Click on selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	1500.00	kW	
Time after ignition (t)	5.00	min.	300 sec

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-139.

$$\Delta T_g = 6.85[Q^2/(A_v(h_v)^{1/2})\,(A_T h_k)]^{1/3}$$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

A_v = **3.38** m^2

Thermal Penetration Time Calculation **Thermally Thin Material**

$t_p = (\rho c_p/k)(\delta/2)^2$

Where ρ = interior construction density (kg/m^3)
c_p = interior construction heat capacity (kJ/kg-K)
k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)

t_p = **91.08** sec

Heat Transfer Coefficient Calculation

$h_k = k/\delta$ for $t > t_p$

Where k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)

h_k = **0.00167** kW/m^2-K

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times lc)] - A_v$

A_T = **98.81** m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

$\Delta T_g = 6.85[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

ΔT_g = **996.67** K

$\Delta T_g = T_g - T_v$

$T_g = \Delta T_g + T_v$

STOP - DO NOT USE THIS WORKSHEET IF HOT GAS LAYER TEMPERATURE EXCEED 1112 °F

T_g = **1294.67** K

T_g =	**1021.67 °C**	**1871.01 °F**	**ANSWER**

ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

$z = ((2kQ^{1/3}t/3A_c) + (1/h_c^{2/3}))^{-3/2}$

Where z = smoke layer height (m)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
h_c = compartment height (m)
A_c = compartment floor area (m^2)
k = a constant given by $k = 0.076/\rho_g$
ρ_g = hot gas layer density (kg/m^3)
ρ_g is given by $\rho_g = 353/T_g$
T_g = hot gas layer temperature (K)

Compartment Area Calculation

$A_c = (w_c)(l_c)$

A_c = **22.30** m^2

Hot Gas Layer Density Calculation

$\rho_g = 353/T_g$

ρ_g = **0.27** kg/m^3

Calculation for Constant K

$k = 0.076/\rho_g$

k = **0.28**

Smoke Gas Layer Height With Natural Ventilation

$z = ((2kQ^{1/3}t/3A_c) + (1/h_c^{2/3}))^{-3/2}$ **STOP - IF Z = VT, SMOKE EXITING VENT**

z =	**0.01 m**	**0.02 ft**	**ANSWER**

If # REF! is given as the smoke layer height then the smoke has completely filled the room

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CHAPTER 3 - METHOD OF ESTIMATING THE HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT FOR A LIQUID POOL FIRE

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	4.00	gallons	0.0151 m^3
Fuel Spill Area or Dike Area (A_{dike})	12.56	ft^2	1.167 m^2
Mass Burning Rate of Fuel (m")	0.017	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	20000	kJ/kg	
Fuel Density (ρ)	796	kg/m^3	
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.20	kg/m^3	

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)
Methanol	0.017	20,000	796
Ethanol	0.015	26,800	794
Butane	0.078	45,700	573
Benzene	0.085	40,100	874
Hexane	0.074	44,700	650
Heptane	0.101	44,600	675
Xylene	0.09	40,800	870
Acetone	0.041	25,800	791
Dioxane	0.018	26,200	1035
Diethy Ether	0.085	34,200	714
Benzine	0.048	44,700	740
Gasoline	0.055	43,700	740
Kerosine	0.039	43,200	820
Diesel	0.045	44,400	918
JP-4	0.051	43,500	760
JP-5	0.054	43,000	810
Transformer Oil, Hydrocarbon	0.039	46,000	760
Fuel Oil, Heavy	0.035	39,700	970
Crude Oil	0.0335	42,600	855
Lube Oil	0.039	46,000	760

Select Fuel Type
Methanol
Scroll to desired fuel type t
Click on selection

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-2.

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-4.

$Q = m''\Delta H_{c,eff} A_f$

Where Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

Heat Release Rate Calculation
$Q = m''\Delta H_c A_f$

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

Q = 396.73 kW 376.03 BTU/sec **ANSWER**

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-197.

$t_b = 4V/\pi D^2 \nu$

Where t_b = burning duration of pool fire (sec)
V = volume of liquid (m^3)
D = pool diameter (m)
ν = regression rate (m/sec)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

$D =$ **1.219** m

Calculation for Regression Rate

$\nu = m''/\rho$

Where m'' = mass burning rate of fuel (kg/m^2-sec)

ρ = liquid fuel density (kg/m^3)

$\nu =$ **0.000021** m/sec

Burning Duration Calculation

$t_b = 4V/\pi D^2 \nu$

t_b =	**607.60 sec**	**10.13 minutes**	**ANSWER**

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 2-10.

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

Where H_f = pool fire flame height (m)

Q = pool fire heat release rate (kW)

D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

H_f =	**1.33 m**	**4.36 ft**	**ANSWER**

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-204.

$H_f = 42\, D\, (m''/\rho_a \sqrt{g D})^{0.61}$

Where H_f = pool fire flame height (m)

m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)

ρ_a = ambient air density (kg/m^3)

D = pool fire diameter (m)

g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\, D\, (m''/\rho_a \sqrt{g D})^{0.61}$

H_f =	**1.79 m**	**5.87 ft**	**ANSWER**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 4 - METHOD OF ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

The following calculations estimate the line fire flame height against the wall.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	5.00	gallons	0.0189 m^3
Fuel Spill Area or Dike Area (A_{dike})	8.00	ft^2	0.743 m^2
Mass Burning Rate of Fuel (m")	0.054	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	43000	kJ/kg	

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)
Methanol	0.017	20,000
Ethanol	0.015	26,800
Butane	0.078	45,700
Benzene	0.085	40,100
Hexane	0.074	44,700
Heptane	0.101	44,600
Xylene	0.09	40,800
Acetone	0.041	25,800
Dioxane	0.018	26,200
Diethy Ether	0.085	34,200
Benzene	0.048	44,700
Gasoline	0.055	43,700
Kerosene	0.039	43,200
Diesel	0.045	44,400
JP-4	0.051	43,500
JP-5	0.054	43,000
Transformer Oil, Hydrocarbon	0.039	46,000
Fuel Oil, Heavy	0.035	39,700
Crude Oil	0.034	42,600
Lube Oil	0.039	46,000

Select Fuel Type

JP-5

Scroll to desired fuel typ

Click on selection

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, Page 3-2.

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-4.

$Q = m''\Delta H_{c,eff}A_f$

Where Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$Q = m''\Delta H_cA_f$

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Q = **1725.77** kW **1635.72** BTU/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where Q' = heat release rate per unit length (kW/m)
Q = fire heat release rate of the fire (kW)
L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W =	0.743	m^2
L =	**0.862**	m

Q' = Q/L

Q' =	**2001.81**	kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: *NFPA Fire Protection Handbook* , 18th Edition, 1997, Page 11-96.

$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$

Where $H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$

$H_{f(wall\ line)}$ =	**2.70 m**	**8.86 ft**	**ANSWER**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, and NFPA Fire Protection Handbook, 18th Edition, 1997. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 5 - METHOD OF ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL IN PRESENCE OF WIND (TILTED FLAME) SOLID FLAME RADIATION MODEL

The following calculations estimate the radiative heat flux from a fire to a target fuel in the presence of wind.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire at ground level to determine if secondary ignitions are likely in presence of wind.
Parameters should be specified ONLY IN THE RED INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Parameter	Value	Unit	Converted
Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg	
Fuel Area or Dike Area (A_{dike})	15.00	ft^2	1.394 m^2
Distance between Fire and Target (L)	10.00	ft	3.048 m
Wind Speed or Velocity (u_w)	700	ft/min	3.56 m/sec
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.20	kg/m^3	
Density of Combustion Products (ρ_c)	0.28	kg/m^3	

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)
Methanol	0.017	20,000
Ethanol	0.015	26,800
Butane	0.078	45,700
Benzene	0.085	40,100
Hexane	0.074	44,700
Heptane	0.101	44,600
Xylene	0.09	40,800
Acetone	0.041	25,800
Dioxane	0.018	26,200
Diethy Ether	0.085	34,200
Benzine	0.048	44,700
Gasoline	0.055	43,700
Kerosine	0.039	43,200
Diesel	0.045	44,400
JP-4	0.051	43,500
JP-5	0.054	43,000
Transformer Oil, Hydrocarbon	0.039	46,000
Fuel Oil, Heavy	0.035	39,700
Crude Oil	0.0335	42,600
Lube Oil	0.039	46,000
Douglas Fir Plywood	0.01082	10,900

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-2.

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL IN PRESENCE OF WIND

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 1995, Page 3-276.

SOLID FLAME RADIATION MODEL IN PRESENCE OF WIND

Where
q" = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to2}$ = view factor between target and the flame in presence of wind

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4 A_{dike}/\pi)}$

D = **1.33** m

Pool Fire Radius Calculation

r = D/2

r = **0.67** m

Flame Emissive Power Calculation

$E = 58 (10^{-0.00823 D})$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = **56.55** kW/m^2

View Factor Calculation in Presence of Wind

$\pi F_{1\to2,H} = (a^2 + (b + 1)^2 - 2 (b + 1 +ab \sin\theta)/(AB)^{0.5} \tan^{-1} (A/B)^{0.5}/((b - 1)/(b + 1))^{0.5} + \sin\theta/(C)0.5 (\tan^{-1} ((ab - (b^2 - 1)\sin\theta)/ (b^2 - 1) (C)^{0.5}) + \tan^{-1} ((b^2 - 1) \sin\theta/(b^2-1)^{0.5} (C)^{0.5})$

$\pi F_{1\to2,V} = (a \cos\theta/(b - a \sin\theta)) (a^2 + (b + 1)^2 - 2b (1 + a \sin\theta))/ (AB)^{0.5} (\tan^{-1} (A/B)^{0.5} ((b - 1)/(b + 1))^{0.5} + \cos\theta/(C)^{0.5} ((\tan^{-1} (ab - (b^2-1) \sin\theta)/((b^2 - 1) (C)^{0.5} + \tan^{-1} (b^2-1) \sin\theta/(b^2 - 1)^{0.5} (C)^{0.5})) - (a \cos\theta)/(b - a \sin\theta) (\tan^{-1} (b - 1/b + 1)$

$a = H_f/r$

$b = R/r$

$A = a^2 + (b +1)^2 - 2a (b + 1) \sin\theta$

$B = a^2 + (b - 1)^2 - 2a (b - 1) \sin\theta$

$C = 1 + (b^2 - 1) \cos^2\theta$

$F_{1\to2,max} = \sqrt{(F^2_{1\to2,H} + F^2_{1\to2,V})}$

Where
$F_{1\to2,H}$ = horizontal view factor
$F_{1\to2,V}$ = vertical view factor
$F_{1\to2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
r = pool fire radius (m)
θ = flame tilt or angle of deflection (radians)

Distance from Center of the Pool Fire to Edge of the Target Calculation

R = L+r = **3.71** m

Heat Release Rate Calculation

$Q = m"\Delta H_c A_f$

Q = **164.35** kW

Pool Fire Flame Height Calculation

$H_f = 55 D (m"/\rho_a \sqrt{(g D)})^{0.67} (u^*)^{-0.21}$

Where
m" = mass burning rate of fuel (kg/m^2-sec)
D = pool fire diameter (m)
ρ_a = ambient air density (kg/m^3)
g = gravitational acceleration (m/sec^2)
u* = nondimensional wind velocity

Nondimensional Wind Velocity Calculation

$u^* = u_w/(g\, m"\, D/\rho_c)^{1/3}$

Where
u_w = wind velocity (m/sec)
g = gravitational acceleration (m/sec^2)
m" = mass burning rate of fuel (kg/m^2-sec)
D = pool fire diameter (m)
ρ_c = density of combustion products (kg/m^3)

$u^* = u_w/(g\, m"\, D/\rho_c)^{1/3}$

u* = **4.466**

$H_f = 55D\ (m''/\rho_a\ (vg\ D))^{0.67}\ (u^*)^{-0.21}$
$H_f =$ **0.96** m

Flame Tilt or Angle of Deflection Calculation

COS θ = 1 for u* = 1
COS θ = 1 / v(u*) for u* = 1

Since u* = 1

q= ACOS(1/(u*)^0.5) = **1.078** Rad 61.76 degree

$a = H_f/r =$ **1.45**
$b = R/r =$ **5.58**
$A = a^2 + (b+1)^2 - 2a\ (b+1)\ \sin\theta =$ **28.57**
$B = a^2 + (b-1)^2 - 2a\ (b-1)\ \sin\theta =$ **11.36**
$C = 1 + (b^2 - 1)\ \cos^2\theta =$ **7.74**

$F_{1\text{->}2,H} =$ **0.161**
$F_{1\text{->}2,V} =$ **0.061**
$F_{1\text{->}2,\ max} = v(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V}) =$ **0.172**

F_{H1}	F_{H2}	F_{H3}	F_{H4}	F_{H5}	F_{H6}		$F_{1\text{->}2,H}$	
0.876	0.997	0.425	0.317	-0.879		1.048	**0.160828**	
F_{V1}	F_{V2}	F_{V3}	F_{V4}	F_{V5}	F_{V6}		F_{V7}	$F_{1\text{->}2,V}$
0.159	1.108	0.923	0.170	-0.879		1.048	0.111	**0.061069**

Radiative Heat Flux Calculation in Presence of Wind

$q'' = EF_{1\text{->}2}$

q" = 9.73 kW/m² **0.86 BTU/ft²-sec** **ANSWER**

CRITICAL HEAT FLUX FOR CABLE FAILURE

Cable Type	Damage Threshold Heat Flux (kW/m²)
IEEE-383 qualified	10
IEEE-383 unqualified	5

Reference: EPRI TR-100370, Fire-Induced Vulnerability Evaluation (FIVE), April 1992, page 10.4-7.

NOTE
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
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CHAPTER 5 - METHOD OF ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITION POINT SOURCE RADIATION MODEL

The following calculations estimate the radiative heat flux from a fire to a target fuel.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire at ground level to determine if secondary ignitions are likely with no wind.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg	
Fuel Area or Dike Area (A_{dike})	20.00	ft^2	1.86 m^2
Distance between Fire and Target (L)	9.00	ft	2.7432 m
Radiative Fraction (χ_r)	0.35		

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)
Methanol	0.017	20,000	796
Ethanol	0.015	26,800	794
Butane	0.078	45,700	573
Benzene	0.085	40,100	874
Hexane	0.074	44,700	650
Heptane	0.101	44,600	675
Xylene	0.09	40,800	870
Acetone	0.041	25,800	791
Dioxane	0.018	26,200	1035
Diethy Ether	0.085	34,200	714
Benzine	0.048	44,700	740
Gasoline	0.055	43,700	740
Kerosine	0.039	43,200	820
Diesel	0.045	44,400	918
JP-4	0.051	43,500	760
JP-5	0.054	43,000	810
Transformer Oil, Hydro	0.039	46,000	760
Fuel Oil, Heavy	0.035	39,700	970
Crude Oil	0.0335	42,600	855
Lube Oil	0.039	46,000	760
Douglas Fir Plywood	0.01082	10,900	500

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-2.

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type
Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-272.

POINT SOURCE RADIATION MODEL

$q'' = Q\,\chi_r / 4\,\pi\,R^2$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χ_r = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

A_{dike} = $\pi D^2/4$

D = $\sqrt{(4\,A_{dike}/\pi)}$

D = **1.54** m

Heat Release Rate Calculation

$Q = m''\Delta H_c A_{dike}$

Where Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A = surface area of pool fire (area involved in vaporization) (m^2)

Q = **219.14** kW

Distance from Center of the Fire to Edge of the Target Calculation

$R = L+D/2$

Where R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = **3.51** m

Radiative Heat Flux Calculation

$q'' = Q\,\chi_r / 4\,\pi\,R^2$

q'' = 0.49 kW/m^2 0.04 BTU/ft^2-sec **ANSWER**

CRITICAL HEAT FLUX FOR CABLES FAILURE

Cable Type	Damage Threshold Heat Flux (kW/m^2)
IEEE-383 qualified	10
IEEE-383 unqualified	5

Reference: EPRI 100370, Fire-Induced Vulnerability Evaluation (FIVE), April 1992, page 10.4-7.

NOTE

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CHAPTER 5 - METHOD OF ESTIMATING THERMAL RADIATION FROM HYDROCARBON FIREBALLS

The following calculations estimate the thermal heat flux from hydrocarbon fuel vapors received by an object.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Mass of Fuel Vapor (m_F)	222.00	lb	100.70 kg
Distance at Ground Level from the Origin (L)	330	ft	100.58 m
Fuel Vapor Density (ρ_F)	3.70	kg/m^3	

THERMAL PROPERTIES DATA

Vapor Densities of Hydrocarbon Fuels at Normal Temperature and Pressure

Fuel	Fuel Vapor Density ρ_F (kg/m^3)
Acetone	2.00
Acetylene	0.90
Benzene	2.80
Butane	2.00
Carbon Monox	1.00
Cyclohexane	29.00
Ethanal	1.50
Ethane	1.00
Ethylene	1.00
Gasoline	3.49
Heptane	3.50
Hexane	3.00
Hydrogen	0.10
Methane	0.60
Methanol	1.10
Octene	3.90
Propane	1.60
Propylene	1.50
Styrene	3.60
Toluene	3.10
Xylene	3.70

Select Fuel Type

Xylene

Scroll to desired fuel type then Click on selection

Reference: NFPA 325, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids, 1994 Edition.

ESTIMATING THERMAL RADIATION FROM HYDROCARBON FIREBALLS HASEGAWA AND SATO METHOD

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-230.

$q''_r = 828\, m_F^{0.771} / R^2$

Where q''_r = thermal radiation from fireball (kW/m^2)
m_F = mass of fuel vapor (kg)
R = distance from the center of the fireball to the target (m)

Volume of the Fireball Fuel Calculation

$V_F = m_F/\rho_F$

Where V_F = volume of fuel vapor (m^3)
m_F = mass of fuel vapor (kg)
ρ_F = fuel vapor density (kg/m^3)

V_F = **27.22** m^3

Fireball Flame Height Calculation

$Z_p = 12.73\ (V_F)^{1/3}$

Where Z_p = height of the maximum visible flame (m)

V_F = volume of fuel vapor (m^3)

Z_p = **38.29** m

Distance from the Center of the Fireball to the Target Calculation

$R = \sqrt{(Z_p^2 + L^2)}$

Where R = distance from center of the fireball to the target (m)

Z_p = height of the maximum visible flame (m)

L = distance at ground level from the origin (m)

R = **107.63** m

Maximum Heat Flux on Target

$q''_r = 828\ m_F^{0.771} / R^2$

q''_r =	**2.50 kW/m^2**	**ANSWER**

Diameter of the Fireball

$D = 5.25\ (m_F)^{0.314}$

Where D = maximum fireball diameter (m)

m_F = mass of fuel vapor (kg)

D =	**22.34 m**	**ANSWER**

Duration of the Fireball

$t_p = 2.8\ V_F^{1/6}$

Where t_p = time of the fireball (sec)

V_F = volume of fuel vapor (m^3)

t_p =	**4.86 sec**	**ANSWER**

NOTE

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CHAPTER 6 - METHOD OF ESTIMATING THE IGNITION TIME OF A TARGET FUEL EXPOSED TO A CONSTANT RADIATIVE HEAT FLUX

The following calculations estimate time to ignition for flame spread of solid fuels exposed to a constant external radiative heat flux.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters.
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INPUT PARAMETERS

MATERIAL FLAME SPREAD PROPERTIES

Material Ignition Temperature (T_{ig})	510.00	°C	
Material Thermal Inertia (kpc)	0.40	$(kW/m^2\text{-}K)^2$-sec	
Material Critical Heat Flux for Ignition ($q''_{critical}$)	28.00	kW/m^2	
Flame Spread Parameter b	0.10	$(s)^{-1/2}$	
Exposure or External Radiative Heat Flux (q''_e)	100.00	kW/m^2	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
Heat Transfer Coefficient at Ignition (h_{ig})	0.0275	kW/m^2-K	

FLAME SPREAD PROPERTIES OF COMMON MATERIALS

Materials	Ignition Temperature T_{ig} (°C)	Thermal Inertia kpc $(kW/m^2\text{-}K)^2$-sec	Critical Heat Flux $q''_{critical}$ (kW/m^2)	Flame Spread Parameter $(s)^{-1/2}$
PMMA Polycast (1.59 mm)	278	0.73	9	0.04
Hardboard (6.35 mm)	298	1.87	10	0.03
Carpet (Arcylic)	300	0.42	10	0.06
Fiber Insulation Board	355	0.46	14	0.07
Hardboard (3.175 mm)	365	0.88	14	0.05
PMMA Type G (1.27 cm)	378	1.02	15	0.05
Asphalt Shingle	378	0.7	15	0.06
Douglas Fire Particle Board (1.27 cm)	382	0.94	16	0.05
Plywood Plain (1.27 cm)	390	0.54	16	0.07
Plywood Plain (0.635 cm)	390	0.46	16	0.07
Foam Flexible (2.54 cm)	390	0.32	16	0.09
GRP (2.24 mm)	390	0.32	16	0.09
Hardboard (Gloss Paint) (3.4 mm)	400	1.22	17	0.05
Hardboard Nitrocellulose Paint)	400	0.79	17	0.06
GRP (1.14 mm)	400	0.72	17	0.06
Particle Board (1.27 cm Stock)	412	0.93	18	0.05
Carpet (Nylon/Wool Blend)	412	0.68	18	0.06
Gypsum Board, Wallboard (S142M)	412	0.57	18	0.07
Carpet # 2 (Wool Untreated)	435	0.25	20	0.11
Foam Rigid (2.54 cm)	435	0.03	20	0.32
Fiberglass Shingle	445	0.5	21	0.08
Polyisoyanurate (5.08 cm)	445	0.02	21	0.36
Carpet # 2 (Wool Treated)	455	0.24	22	0.12
Carpet # 1 (Wool, Stock)	465	0.11	23	0.18
Aircraft Panel Expoxy Fiberite	505	0.24	28	0.13
Gypsum Board FR (1.27 cm)	510	0.4	28	0.1
Polycarbonate (1.52 mm)	528	1.16	30	0.06
Gypsum Board (Common) (1.27 mm)	565	0.45	35	0.11
Plywood FR (1.27 cm)	620	0.76	44	0.1
Polystyrene (5.08 cm)	630	0.38	46	0.14

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 14.

Select Material
Gypsum Board FR (1.27 cm)
Scroll to desired material then Click on selection

METHOD OF MIKKOLA AND WICHMAN
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 7.

$t_{ig} = \pi/4\ k\rho c\ (T_{ig} - T_a)^2 / (q_e'' - q_{critical}'')^2$

Where
t_{ig} = material ignition time (sec)
$k\rho c$ = material thermal inertia $(kW/m^2\text{-}K)^2$-sec
T_{ig} = material ignition temperature (°C)
T_a = ambient air temperature (°C)
q_e'' = exposure or external heat flux (kW/m^2)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)

$t_{ig} = \pi/4\ k\rho c\ (T_{ig} - T_a)^2 / (q_e'' - q_{critical}'')^2$

t_{ig} = 14.26 sec 0.24 minute **ANSWER**

METHOD OF QUINTIERE AND HARKLEROAD
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 12.

$t_{ig} = (q_{critical}'' / b\ q_e'')^2$

Where
t_{ig} = material ignition time (sec)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)
b = flame spread parameter $(s)^{-1/2}$
q_e'' = exposure or external heat flux (kW/m^2)

$t_{ig} = (q_{critical}'' / b\ q_e'')^2$

t_{ig} = 7.84 sec 0.13 minute **ANSWER**

METHOD OF JANSSENS
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 15.

$t_{ig} = 0.563\ (k\rho c / h_{ig}^2)\ ((q_e'' / q_{critical}'')\text{-}1)^{-1.83}$

Where
t_{ig} = material ignition time (sec)
$k\rho c$ = material thermal inertia $(kW/m^2\text{-}K)^2$-sec
h_{ig} = heat transfer coefficient at ignition $(kW/m^2\text{-}K)$
q_e'' = exposure or external heat flux (kW/m^2)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)

$t_{ig} = 0.563\ (k\rho c / h_{ig}^2)\ ((q_e'' / q_{critical}'')-1)^{-1.83}$

t_{ig} =	**52.88 sec**	**0.88 minute**	**ANSWER**

SUMMARY OF RESULTS

METHOD OF MIKKOLA AND WICHMAN	**0.24** minute
METHOD OF QUINTIERE AND HARKLEROAD	**0.13** minute
METHOD OF JANSSENS	**0.88** minute

NOTE

The above calculations are based on principles developed in the SFPE Engineering Guide "Piloted Ignition of Solid Materials Under Radiant Exposure," January 2002.
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CHAPTER 7 - METHOD OF ESTIMATING FULL-SCALE HEAT RELEASE RATE OF A CABLE TRAY FIRE

The following calculations estimate the full-scale cable tray heat release rate.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs})	299	kW/m^2	
Exposed Cable Tray Burning Area (A_f)	10.80	ft^2	1.003 m^2

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area Q''_{bs} (kW/m^2)
Id PE	1071
PE/PVC	589
XPE/FRXPE	475
PE/PVC	395
PE/PVC	359
XPE/Neoprene	354
PE, PP/Cl.S.PE	345
PE/PVC	312
XPE/Neoprene	302
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
FRXPE/Cl.S.PE	258
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
XPE/Cl.S.PE	204
Silicone, glass braid, asb	182
XPE/XPE	178
PE, PP/Cl.S.PE	177
Silicone, glass braid	128
Teflon	98

Select Cable Type

PE, PP/Cl.S.PE

Scroll to desired cable type then Click on selection

Reference: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition 1995, Page 3-12.

$Q_{fs} = 0.45\ Q_{bs}\ A_f$

Where Q_{fs} = cable tray full-scale HRR (kW)
Q_{bs} = cable tray bench-scale HRR (kW)
A_f = exposed cable tray burning area (m^2)

Heat Release Rate Calculation

$Q_{fs} = 0.45\ Q_{bs}\ A_f$

Q_{fs} = 135.00 kW 127.96 BTU/sec **ANSWER**

NOTE

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CHAPTER 8 - METHOD OF ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (m_{solid})	200.00	lb	90.72	kg
Exposed Fuel Surface Area (A_{fuel})	100.00	ft^2	9.29	m^2
Heat Release Rate per Unit Floor Area (Q")	589	kW/m^2		
Effective Heat of Combustion ($\Delta H_{c,eff}$)	24000	kJ/kg		

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Materials	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
PE/PVC	589	24000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
PE, Nylon/PVC, Nylon	231	9200
Teflon	98	3200
Douglas fir plywood	221	17600
Fire retardant treated plywood	81	13500
Particleboard, 19 mm thick	1900	17500
Nylon 6/6	1313	32000
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyethylene (PE)	1408	46500
Polycarbonate	420	24400
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-butadiene Copolymers (SB	163	44000
Ethylene Propylene Dien Rubber (	956	28800
Empty Cartons 15 ft high	1700	12700
Wood pallets, stacked 1.5 ft high	1420	14000
Wood pallets, stacked 5 ft high	3970	14000
Wood pallets, stacked 10 ft high	6800	14000

Select Material

PE/PVC

Scroll to desired material then Click on selection

References: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.
Karlsson and Quantiere, *Enclosure Fire Dynamics*, Chapter 3,: Energy Release Rate," CRC Press, 1999.
Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.
Hirschler, M, M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: *NFPA Fire Protection Handbook*, 18th Edition, 1997.

$t_{solid} = (m_{Fuel}\ \Delta H_c)/(Q''\ A_{Fuel})$

Where m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)
Q" = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed fuel surface area (m^2)

$t_{solid} = (m_{solid}\ \Delta H_c)/(Q''\ A_{solid})$

t_{solid} = 397.89 sec 6.63 minutes* **ANSWER**

***Note: In fires, combustion is never complete, leaving some residual fuel, therefore this method provides a reasonable burning duration for solid fuel.**

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 18th Edition, 1997. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 9 - METHOD OF ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

The following calculations estimate the centerline plume temperature in a compartment fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1420.00	kW	
Evaluation Above the Fire Source (z)	20.00	ft	6.10 m
Area of Combustible Fuel (A_c)	10.00	ft^2	0.93 m^2

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.20	kg/m^3	
Acceleration of Gravity (g)	9.81	m/sec^2	
Convective Heat Release Fraction (χ_c)	0.50		

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 2-9.

$$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

Where Q_c = convective portion of the heat release rate (kW)
T_a = ambient air temperature (K)
g = acceleration of gravity (m/sec^2)
c_p = specific heat of air (kJ/kg-K)
ρ_a = ambient air density (kg/m^3)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\,Q$$

Where Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction
Q_c = **710** kW

Pool Fire Diameter Calculation

A_c = $\pi D^2/4$
D = $\sqrt{(4\,A_c/\pi)}$
D = **1.09** m

Hypothetical Virtual Origin Calculation

$z_0/D = -1.02 + 0.083\,(Q^{2/5})/D$

Where z_0 = virtual origin of the fire (m)
Q = heat release rate of fire (kW)
D = diameter of pool fire (m)

z_0/D = 0.37
z_0 = **0.40** m

Centerline Plume Temperature Calculation

$$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

$T_{p(centerline)} - T_a$ = **110.29**

$T_{p(centerline)}$ = 408.29 K

$T_{p(centerline)}$ =	**135.29 °C**	**275.52 °F**	**ANSWER**

NOTE

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CHAPTER 10 - METHOD OF ESTIMATING SPRINKLER RESPONSE TIME

The following calculations estimate sprinkler activation time.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
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INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	800.00	kW
Sprinkler Response Time Index (RTI)	42	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	275	°F
Distance from the Top of the Fuel Package to the Ceiling (H)	10.00	ft
Radial Distance from the Plume Centerline to the Sprinkler (r)	10.00	ft
Ambient Air Temperature (T_a)	68.00	°F

Convective Heat Release Fraction (χ_c) 0.70

r/H = 1.00

GENERIC SPRINKLER RESPONSE TIME INDEX (RTI)*

Common Sprinkler Type	Generic Response Time Index RTI $(m\text{-}sec)^{1/2}$
Standard response bulb	235
Standard response link	130
Quick response bulb	42
Quick response link	34

Select Type of Sprinkler
Quick response bulb
Scroll to desired sprinkler type then Click on selecti

Reference: Madrzykowski, D., "Evaluation of Sprinkler Activation Prediction Methods" ASIAFLAM'95, International Conference on Fire Science and Engineering, 1st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.

***Note: The actual RTI should be used when the value is available.**

GENERIC SPRINKLER TEMPERATURE RATING ($T_{activation}$)*

Temperature Classification	Range of Temperature Ratings (°F)	Generic Temperature Ratings (°F)
Ordinary	135 to 170	165
Intermediate	175 to 225	212
High	250 to 300	275
Extra high	325 to 375	350
Very extra high	400 to 475	450
Ultra high	500 to 575	550
Ultra high	650	550

Select Sprinkler Clas
High
Scroll to desired sprir then Click on selectio

Reference: Automatic Sprinkler Systems Handbook, 6th Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.

***Note: The actual temperature rating should be used when the value is available.**

ESTIMATING SPRINKLER RESPONSE TIME

Reference: *NFPA Fire Protection Handbook*, 18th Edition, 1997, Page 11-97.

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

Where $t_{activation}$ = sprinkler activation response time (sec)
RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9\ (Q_c)^{2/3}/H^{5/3}$ for r/H = 0.18

$T_{jet} - T_a = 5.38\ (Q_c/r)^{2/3}/H$ for r/H > 0.18

Where T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
Q_c = convective portion of the heat release rate (kW)

H = distance from the top of the fuel package to the ceiling level (m)
r = radial distance from the plume centerline to the sprinkler (m)

Convective Heat Release Rate Calculation
$Q_c = \chi_c Q$

Where Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction

Q_c = 560 kW

Radial Distance to Ceiling Height Ratio Calculation
r/H = 1.00 r/H > 0.15

$T_{jet} - T_a$ = {5.38 (Qc/r)^2/3}/H
$T_{jet} - T_a$ = 57.04
T_{jet} = 77.04 (°C)

Ceiling Jet Velocity Calculation
$u_{jet} = 0.96\ (Q/H)^{1/3}$ for r/H = 0.15
$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for r/H > 0.15

u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = distance from the top of the fuel package to the ceiling (m)
r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation
r/H = 1.00 r/H > 0.15

u_{jet} = (0.195 Q^1/3 H^1/2)/r^5/6
u_{jet} = 1.249 m/sec

Sprinkler Activation Time Calculation

$t_{activation} = (RTI/(v u_{jet}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$
$t_{activation}$ = #NUM! sec

The sprinkler will respond in approximately	**#NUM!**	**minutes**	**ANSWER**

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE
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3.05	m
20.00	°C
293.00	K

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CHAPTER 13 - METHOD OF PREDICTING COMPARTMENT POST-FLASHOVER TEMPERATURE

The following calculations estimate the compartment post-flashover temperature.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
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INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	100.00	ft	30.48 m
Compartment Length (l_c)	18.00	ft	5.4864 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	3.00	ft	0.914 m
Vent Height (h_v)	8.00	ft	2.438 m

PREDICTING COMPARTMENT POST-FLASHOVER TEMPERATURE
METHOD OF LAW

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-142.

$T_{PFO\ (max)} = 6000\ (1 - e^{-0.1\Omega})/(\sqrt{\Omega})$

Where $T_{PFO\ (max)}$ = maximum compartment post-flashover temperature (°C)
Ω = ventilation factor

Where $\Omega = (A_T - A_v)/A_v\ (\sqrt{h_v})$
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$A_v = (w_v)\ (h_v)$

Where A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

$A_v =$ **2.23** m^2

Area of Compartment Enclosing Surface Boundaries

$A_T = [2\ (w_c \times l_c) + 2\ (h_c \times w_c) + 2\ (h_c \times l_c)] - A_v$

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)
A_v = area of ventilation opening (m^2)

$A_T =$ **551.47** m^2

Ventilation Factor Calculation

$\Omega = (A_T - A_v)/A_v\ (\sqrt{h_v})$

Where Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

$\Omega =$ **157.75** $m^{-1/2}$

Compartment Post-Flashover Temperature Calculation

$T_{PFO\ (max)} = 6000\ (1 - e^{-0.1\Omega})/(\sqrt{\Omega})$

$T_{PFO\ (max)}$ = 477.71 °C 891.88 °F **ANSWER**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 14 - METHOD OF ESTIMATING PRESSURE RISE DUE TO A FIRE IN A CLOSED COMPARTMENT

The following calculations estimate the pressure rise in a compartment due to fire and combustion.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG guide should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	10.00	ft	3.05 m
Compartment Length (l_c)	12.00	ft	3.66 m
Compartment Height (h_c)	10.00	ft	3.05 m
Fire Heat Release Rate (Q)	100.00	kW	
Time after Ignition (t)	10.00	sec	

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	68.00	°F	20.00 °C 293.00 K
Initial Atmospheric Pressure (P_a)	14.70	psi	101.35 kPa
Specific Heat of Air at Constant Volume (c_v)	0.70	kJ/kg-K	
(Note: Values of c_v ranges from 0.71 to 0.85 kJ/kg-k)			
Ambient Air Density (ρ_a)	1.20	kg/m^3	

METHOD OF KARLSSON AND QUINTIERE

Reference: Karlsson and Quintiere, *Enclosure Fire Dynamics*, 1999, Page 192.

$(P-P_a)/P_a = Qt/(V\rho_a c_v T_a)$

Where
P = compartment pressure due to fire and combustion (kPa)
P_a = initial atmospheric pressure (kPa)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
V = compartment volume (m^3)
ρ_a = ambient density (kg/m^3)
c_v = specific heat of air at constant volume (kJ/kg-K)
T_a = ambient air temperature (K)

Compartment Volume Calculation

$V = w_c \times l_c \times h_c$

Where
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = **33.98** m^3 **1200** ft^3

Pressure Rise in Compartment

$(P-P_a)/P_a = Qt/(V\rho_a c_v T_a)$
$(P-P_a)/P_a =$ **0.120** atm
Multiplying by the atmospheric pressure (P_a) = 101 kPa
Gives a pressure difference = **12.12 kPa** **1.76 psi**
ANSWER

This example shows that in a very short time the pressure in a closed compartment rises to quite large value.

Most buildings have leaks of some sort. The above example indicates that even though a fire compartment may be closed, the pressure is very rapid and would presumably lead to sufficient leaks to prevent further pressure rise from occurring. We will use this conclusion when dealing with pressure rises in enclosures with small leaks.

NOTE
The above calculations are based on principles developed in the Enclosure Fire Dynamics. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation,

there is no absolute guarantee of the accuracy of these calculations.
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CHAPTER 15 - METHOD OF ESTIMATING PRESSURE AND EXPLOSIVE ENERGY RELEASE

The following calculations estimate the pressure and energy due to an explosion in a confined space.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cells(s). The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	4050	°F	2232.22 °C 2505.22 K
Heat of Combustion of the Fuel (ΔH_c)	45790	kJ/kg	
Yield (α), i.e., the fraction of available combustion 1 percent for unconfined mass release and 100 percent for confined vapor release energy participating in blast wave generation	100.00	%	1
Mass of Flammable Vapor Release (m_F)	48.00	lb	21.82 kg

AMBIENT CONDITIONS

Ambient Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Initial Atmospheric Pressure (P_a)	14.70	psi	101.35 kPa

THERMAL PROPERTIES FOR FUELS

FLAMMABILITY DATA FOR FUELS

Fuel	Adiabatic Flame Temperature T_{ad} (°F)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	4779	48,220
Carbon Monox	4329	10,100
Ethane	2244	47,490
Ethylene	4152	47,170
Hydrogen	4085	130,800
Methane	2143	50,030
n-Butane	2442	45,720
n-Heptane	2586	44,560
n-Pentane	2356	44,980
n-Octane	2478	44,440
Propane	2338	46,360
Propylene	4050	45,790

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Propylene

Scroll to desired fuel type then Click on selection

METHOD OF ZALOSH

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-312.

Pressure Rise from an Confined Explosion

$(P_{max})/P_a = (T_{ad}/T_a)$

Where P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

$P_{max} = (T_{ad}/T_a)\ P_a$

P_{max} = 852.05 kPa 123.58 psi ANSWER

Blast Wave Energy Calculation

$E = \alpha\ \Delta H_c\ m_F$

Where E = blast wave energy (Trinitrotoluene (TNT) equivalent Energy (kJ)

α = yield, i.e., the fraction of available combustion energy participating in blast wave generation
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E =	**999054.55 kJ**	**ANSWER**

TNT Mass Equivalent Calculation

W_{TNT} = E/4500

Where W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} =	**222.01 kg**	**489.45 lb**	**ANSWER**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 16 - METHOD OF CALCULATING THE RATE OF HYDROGEN GAS GENERATION IN BATTERY ROOMS

The following calculations estimate the hydrogen gas generation in battery rooms.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

BATTERY INFORMATION

Float Current (F_C)	60	mA per 100 A_H @ 8-hr. rate
Ampere Hours (A_H)	3730.00	Ampere hours
Number of Cells (N)	60.00	
Constant (K)	0.000267	ft^3

COMPARTMENT INFORMATION

Compartment Width (w_c)	26.00	ft
Compartment Length (l_c)	50.00	ft
Compartment Height (h_c)	12.00	ft
Volume of Enclosure (V)	15600	ft^3

FLAMMABLE GAS INFORMATION

Flammability Limit of Gas or Vapor	2.00	Percent	0.020

Float Current Demand of Fully Charged Stationary Lead-Acid Cells

Reference: Yuasa, Inc., Safety Storage, Installation, Operation, and Maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.

New Antimony Charge Voltage (VPC)	F_C* Antimony New
2.15	15
2.17	19
2.20	26
2.23	37
2.25	45
2.27	60
2.33	120
2.37	195
2.41	300

Select Charge Current Value

2.27

Scroll to desired value then Click on selection

*(milliamperes per 100 AH @ 8-hr. rate)

Old Antimony Charge Voltage (VPC)	F_C* Antimony Old
2.15	60
2.17	80
2.20	105
2.23	150
2.25	185
2.27	230
2.33	450
2.37	700
2.41	1100

Select Charge Current Value

Scroll to desired value then Click on selection

*(milliamperes per 100 AH @ 8-hr. rate)

Calcium Charge Voltage (VPC)	F_C* Antimony Calcium
2.15	
2.17	4
2.20	6
2.23	8

Select Charge Current Value

Scroll to desired value then Click on selection

2.25	11
2.27	12
2.33	24
2.37	38
2.41	58

*(milliamperes per 100 AH @ 8-hr. rate)

METHOD OF YUSHA, INC.

Reference: Yuasa, Inc., *Safety Storage, Installation, Operation, and Maintenance Manual* , Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.

Estimating Hydrogen Gas Generation Rate

$H_{2(gen)} = F_C/1000 \times A_H/100 \times K \times N$

Where
$H_{2(gen)}$ = hydrogen gas generation rate (ft^3/min)
F_C = float current (mA per 100 A_H @ 8-hr. rate)
A_H = ampere hours (normal 8 hour)
K = constant - 1 A_H = 0.000267 ft^3
N = number of cells

$H_{2(gen)}$ = 0.072 ft^3/min **ANSWER**

Estimating Hydrogen Gas in Compartment Based on Given Flammability Limit

$H_{2(comp)} = V \times FL$

Where
$H_{2(comp)}$ = hydrogen gas in compartment (ft^3)
V = volume of compartment (ft^3)
FL = hydrogen gas flammability limit

$H_{2(comp)}$ = 312 ft^3

Estimating Time Required to Reach Hydrogen Concentration on Given Flammability Limit

$t_{H2} = H_{2(comp)}/H_{2(gen)}$

Where
t_{H2} = time require to reach on given flammability limit (min)
$H_{2(comp)}$ = hydrogen gas in compartment (ft^3)
$H_{2(gen)}$ = hydrogen gas generation rate (ft^3/min)

t_{H2} = 4351.13 min 73 hours **ANSWER**

NOTE
The above calculations are based on method presented in the Yuasa, Inc., Safety Storage, Installation, Operation, and maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 17 - METHOD OF ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

The following calculations estimate the fire resistance time for structural steel beams protected by board type fire protection insulating material.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet, and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Ratio of Weight of Steel Section per Linear Foot and Heated Perimeter (W/D)	7.96	lb/ft^2	
Thickness of Spray-Applied Protection on Steel Beam (h) **h = 1/16 in**	3.0000	in	0.250 ft
Density of Spray-Applied Material (ρ_i)	150.00	lb/ft^3	
Thermal Conductivity of Spray-Applied Material (k_i)	0.92480	Btu/ft-hr-°F	0.000256889 Btu/ft-sec-°F
Specific Heat of Spray-Applied Material (c_i)	0.1793	Btu/lb-°F	
Ambient Air Temperature (T_a)	77	°F	
Specific Heat of Steel (c_s)	0.132	Btu/lb-°F	

SECTIONAL FACTORS FOR STEEL BEAMS

Select Beam

6x16

Scroll to desired beam size then Click on selection,

THERMAL PROPERTIES OF BOARD TYPE INSULATION MATERIALS

Select Insulation Type

Concrete

Scroll to desired material then Click on selection

Insulation Material Board	Density ?$_i$ (lb/ft^3)	Thermal Cond. k_i (Btu/ft-hr-°F)	Specific Heat c_i (Btu/lb-°F)
Fiber-silicate, fiber-calcium silicate	38	0.0867	0.2868
Gypsum plaster	50	0.1156	0.4063
Mineral wool, fiber silicate	10	0.1156	0.2868
Concrete	150	0.9248	0.1793

Reference: Buchanan, A. H., Structural Design for Fire Safety, 2001, (Page. 182).

ESTIMATING FIRE RESISTANCE TIME USING QUASI-STEADY-STATE APPROACH

Reference: "Analytical Methods for Determining Fire Resistance of Steel Members," SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, page 4-187.

Temperature Rise in Steel Beam

$\Delta T_s = (k_i/(c_s\, h\, W/D + 1/2 c_i \rho_i h^2))\,(T_f - T_s)\,\Delta t$

Where
ΔT_s = temperature rise in steel (°F)
k_i = thermal conductivity of insulation material (Btu/ft-sec-°F)
ρ_i = density of insulation material
c_i = specific heat of insulation material (Btu/lb-°F)
c_s = specific heat of steel (Btu/lb-°F)
h = thickness of protection on steel beam (in)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
T_f = fire exposure temperature (°F)
T_s = steel temperature (°F)
Δt = time step (sec)

The Maximum Allowable Time Step

$\Delta t = 15.9\ W/D$
$\Delta t =$ 127 sec
$\Delta t =$ 2.11 minutes

For ASTM-E-119 exposure, T_f at any time, t, is given by the following expression

$T_f = C_1\ \mathrm{LOG}\ (0.133\, t + 1) + T_a$

Where
T_f = fire exposure temperature (°F)
C_1 = constant = 620
t = time step (sec)
T_a = ambient air temperature (°F)

$\Delta T_{s1} = (k_i/(c_s\, h\, W/D + 1/2 c_i \rho_i h^2))\,((C_1\ \mathrm{LOG}\ (0.133\, t_1 + 1)+T_a) - T_{s0})\,\Delta t$

Where $t_1 = \Delta t/2$

T_{s0} = initial steel temperature (°F)

$\Delta T_{s2} = (k_i/(c_s\ h\ W/D + 1/2 c_i \rho_i h^2))\ ((C_1\ LOG\ (0.133\ t_2 + 1) + T_a) - T_s)\ \Delta t$

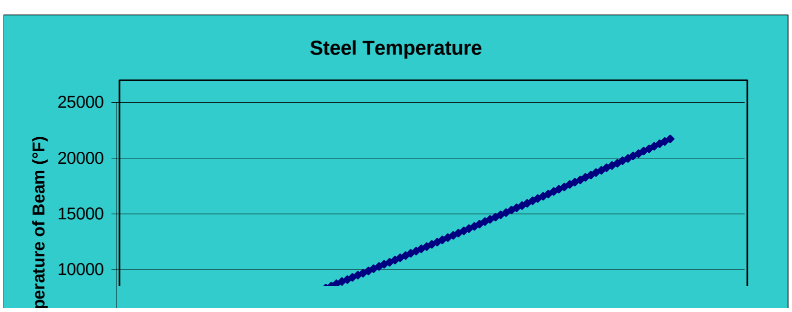
Where $t_2 = t_1 + \Delta t/2$

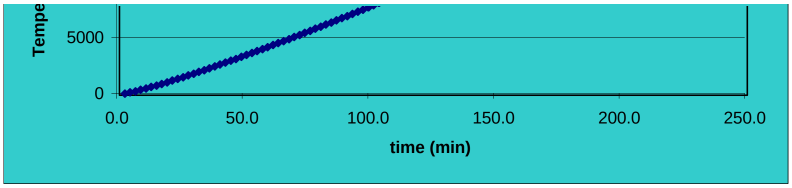
$T_s = T_{s0} + \Delta T_s$ from previous row

Results:

Time (min)	Time (sec)	DT_s (°F)	T_s (°F)	
2.1	127	73	150	
4.2	253	98	248	
6.3	380	111	359	
8.4	506	120	480	
10.5	633	127	607	
12.7	759	133	740	
14.8	886	138	877	
16.9	1012	142	1019	failure of beam
19.0	1139	145	1164	failure of beam
21.1	1265	148	1313	failure of beam
23.2	1392	151	1464	failure of beam
25.3	1518	154	1618	failure of beam
27.4	1645	156	1774	failure of beam
29.5	1771	158	1933	failure of beam
31.6	1898	161	2093	failure of beam
33.7	2024	162	2256	failure of beam
35.8	2151	164	2420	failure of beam
38.0	2277	166	2586	failure of beam
40.1	2404	168	2753	failure of beam
42.2	2530	169	2923	failure of beam
44.3	2657	171	3093	failure of beam
46.4	2783	172	3265	failure of beam
48.5	2910	173	3438	failure of beam
50.6	3036	174	3613	failure of beam
52.7	3163	176	3788	failure of beam
54.8	3289	177	3965	failure of beam
56.9	3416	178	4143	failure of beam
59.0	3542	179	4322	failure of beam
61.1	3669	180	4502	failure of beam
63.3	3795	181	4683	failure of beam
65.4	3922	182	4866	failure of beam
67.5	4048	183	5049	failure of beam
69.6	4175	184	5232	failure of beam
71.7	4302	185	5417	failure of beam
73.8	4428	186	5603	failure of beam
75.9	4555	186	5789	failure of beam
78.0	4681	187	5976	failure of beam
80.1	4808	188	6165	failure of beam
82.2	4934	189	6353	failure of beam
84.3	5061	190	6543	failure of beam
86.5	5187	190	6733	failure of beam
88.6	5314	191	6924	failure of beam
90.7	5440	192	7116	failure of beam
92.8	5567	192	7308	failure of beam
94.9	5693	193	7501	failure of beam
97.0	5820	194	7695	failure of beam
99.1	5946	194	7889	failure of beam
101.2	6073	195	8084	failure of beam
103.3	6199	196	8280	failure of beam
105.4	6326	196	8476	failure of beam
107.5	6452	197	8672	failure of beam
109.6	6579	197	8870	failure of beam

Time (min)	Time (sec)	DT_s (°F)	T_s (°F)	
111.8	6705	198	9067	failure of beam
113.9	6832	198	9266	failure of beam
116.0	6958	199	9465	failure of beam
118.1	7085	199	9664	failure of beam
120.2	7211	200	9864	failure of beam
122.3	7338	200	10064	failure of beam
124.4	7464	201	10265	failure of beam
126.5	7591	201	10467	failure of beam
128.6	7717	202	10669	failure of beam
130.7	7844	202	10871	failure of beam
132.8	7970	203	11074	failure of beam
134.9	8097	203	11277	failure of beam
137.1	8223	204	11481	failure of beam
139.2	8350	204	11685	failure of beam
141.3	8476	205	11890	failure of beam
143.4	8603	205	12095	failure of beam
145.5	8730	206	12301	failure of beam
147.6	8856	206	12507	failure of beam
149.7	8983	206	12713	failure of beam
151.8	9109	207	12920	failure of beam
153.9	9236	207	13127	failure of beam
156.0	9362	208	13335	failure of beam
158.1	9489	208	13543	failure of beam
160.3	9615	208	13751	failure of beam
162.4	9742	209	13960	failure of beam
164.5	9868	209	14169	failure of beam
166.6	9995	210	14378	failure of beam
168.7	10121	210	14588	failure of beam
170.8	10248	210	14798	failure of beam
172.9	10374	211	15009	failure of beam
175.0	10501	211	15220	failure of beam
177.1	10627	211	15431	failure of beam
179.2	10754	212	15643	failure of beam
181.3	10880	212	15855	failure of beam
183.4	11007	212	16067	failure of beam
185.6	11133	213	16280	failure of beam
187.7	11260	213	16493	failure of beam
189.8	11386	213	16706	failure of beam
191.9	11513	214	16920	failure of beam
194.0	11639	214	17134	failure of beam
196.1	11766	214	17348	failure of beam
198.2	11892	215	17563	failure of beam
200.3	12019	215	17778	failure of beam
202.4	12145	215	17993	failure of beam
204.5	12272	216	18208	failure of beam
206.6	12398	216	18424	failure of beam
208.7	12525	216	18640	failure of beam
210.9	12651	216	18857	failure of beam
213.0	12778	217	19073	failure of beam
215.1	12905	217	19290	failure of beam
217.2	13031	217	19507	failure of beam
219.3	13158	218	19725	failure of beam





The Failure Temperature for Steel Beams is 1000 °F

NOTE

The above calculations are based on principles developed in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 2nd Edition 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 17 - METHOD OF ESTIMATING FIRE RESISTANCE TIME OF UNPROTECTED STEEL BEAMS (QUASI-STEADY-STATE APPROACH)

The following calculations estimate the fire resistance time for unprotected structural steel beams.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet, and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

The Ratio of Heated Surface Area to Volume of Beam (both per unit length) (F/V)	57.84	m^{-1}	
Flame Emissivity (ε_f)	0.50		
Specific Heat of Steel (c_s)	600.00	J/kg-K	
Density of Steel (ρ_s)	7850.00	kg/m^3	
Convective heat Transfer Coefficient (h_c)	25.00	W/m^2-K	
Stefan Boltzmann Constant	5.669E-08	W/m^2-K^4	
Ambient Air Temperature (T_a)	20.00	°C	293 K
Constant (C_1)	345.00		

SECTIONAL FACTORS FOR STEEL BEAMS

Select Beam

36x280

Scroll to desired beam size then Click on selection

EMISSIVITY VALUES FOR DIFFERENT CONSTRUCTION TYPES

Type of Construction	Emissivity e_f
Beam outside façade	0.3
Floor girder with floor slab of concrete, only the underside of the bottom flange being directly exposed to fire	0.3
Floor girder with floor slab on the top flange Girder of I section for which the width-depth ratio is not less than 0.5	0.5
Floor girder with floor slab on the top flange Girder of I section for which the width-depth ratio is less than 0.5	0.7
Floor girder with floor slab on the top flange Box girder and lattice	0.7
Beam exposed to fire on all sides	0.7

Select Flame Emissivity, e_f

0.5

Scroll to desired construction type then Click on selection

ESTIMATING FIRE RESISTANCE TIME OF UNPROTECTED STEEL BEAMS USING QUASI-STEADY-STATE APPROACH

Reference: "Buchanan, A. H., Structural Design for Fire Safety, John Wiley & Sons, Limited, 2001, p. 179.

$$\Delta T_s = F/V\ 1/\rho_s c_s\ (h_c\ (T_f - T_s) + \sigma\ \varepsilon\ (T_f^4 - T_s^4))\ \Delta t$$

Where
ΔT_s = temperature rise in steel (°F)
F/V = ratio of heated surface area to volume of beam (both per unit length) (m^{-1})
ρ_s = density of steel (kg/m^3)
c_s = specific heat of steel (J/kg-K)
h_c = convective heat transfer coefficient (W/m^2-K)
σ = Stefan Boltzmann Constant (kW/m^2-K^4)
ε = flame emissivity
T_f = fire exposure temperature (°F)
T_s = steel temperature (°F)
Δt = time step (sec)

The Maximum Allowable Time Step
Δt = 30 **sec**

For ASTM-E-119 exposure, T_f at any time, t, is given by the following expression
$T_f = C_1$ LOG $(0.133\ t + 1) + T_0$
Where T_f = fire exposure temperature (°F)

C_2 = constant = 620
t = time step (sec)
T_a = ambient air temperature (°F)

$\Delta T_{s1} = F/V\ 1/\rho_s c_s (h_c (C_1 \text{ LOG } (0.133\ t_1 + 1) + T_a) - T_{s0}) + \sigma\ \varepsilon\ ((C1 \text{ LOG } (0.133\ t_1 + 1) + T_a)^4 - T_{s0}^4))\ \Delta t$

Where $t_1 = \Delta t/2$
T_{s0} = initial steel temperature (°F)

$\Delta T_{s2} = F/V\ 1/\rho_s c_s (h_c (C_1 \text{ LOG } (0.133\ t_2 + 1) + T_a) - T_s) + \sigma\ \varepsilon\ ((C1 \text{ LOG } (0.133\ t_2 + 1) + T_a)^4 - T_s^4))\ \Delta t$

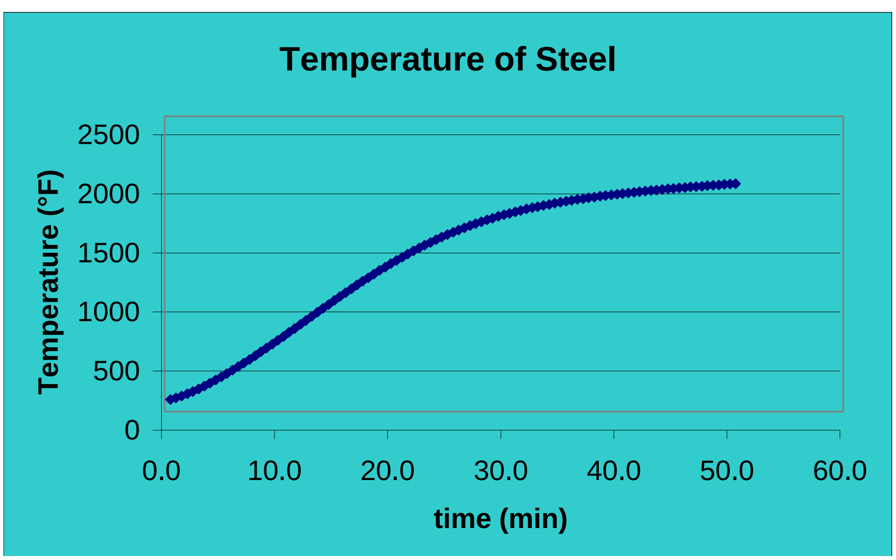
Where $t_2 = t_1 + \Delta t/2$
$T_s = T_{s0} + \Delta T_s$ from previous row

Results

time (min)	T_S (°F)	
0.5	103	
1.0	116	
1.5	132	
2.0	151	
2.5	171	
3.0	193	
3.5	216	
4.0	241	
4.5	267	
5.0	294	
5.5	322	
6.0	351	
6.5	380	
7.0	411	
7.5	442	
8.0	473	
8.5	505	
9.0	538	
9.5	570	
10.0	604	
10.5	637	
11.0	671	
11.5	704	
12.0	738	
12.5	772	
13.0	806	
13.5	840	
14.0	874	
14.5	908	
15.0	941	
15.5	974	
16.0	1007	failure
16.5	1040	failure
17.0	1072	failure

time (min)	T_S (°F)	
17.0	1072	failure
17.5	1103	failure
18.0	1134	failure
18.5	1165	failure
19.0	1195	failure
19.5	1224	failure
20.0	1253	failure
20.5	1281	failure
21.0	1308	failure
21.5	1334	failure
22.0	1360	failure
22.5	1385	failure
23.0	1409	failure
23.5	1432	failure
24.0	1455	failure
24.5	1477	failure
25.0	1498	failure
25.5	1518	failure
26.0	1537	failure
26.5	1556	failure
27.0	1574	failure
27.5	1591	failure
28.0	1607	failure
28.5	1623	failure
29.0	1638	failure
29.5	1652	failure
30.0	1665	failure
30.5	1678	failure
31.0	1691	failure
31.5	1703	failure
32.0	1714	failure
32.5	1725	failure
33.0	1735	failure
33.5	1745	failure

time (min)	T_S (°F)	
34.0	1755	failure
34.5	1764	failure
35.0	1772	failure
35.5	1780	failure
36.0	1788	failure
36.5	1796	failure
37.0	1803	failure
37.5	1810	failure
38.0	1817	failure
38.5	1823	failure
39.0	1829	failure
39.5	1835	failure
40.0	1841	failure
40.5	1847	failure
41.0	1852	failure
41.5	1857	failure
42.0	1862	failure
42.5	1867	failure
43.0	1872	failure
43.5	1876	failure
44.0	1881	failure
44.5	1885	failure
45.0	1889	failure
45.5	1893	failure
46.0	1897	failure
46.5	1901	failure
47.0	1905	failure
47.5	1909	failure
48.0	1912	failure
48.5	1916	failure
49.0	1919	failure
49.5	1923	failure
50.0	1926	failure
50.5	1930	failure



The Failure Temperature for Steel Beams is 1000 °F

NOTE

The above calculations are based on principles developed in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 2nd Edition 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 17 - METHOD OF ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

The following calculations estimate the fire resistance time for structural steel beams protected by spray-applied fire protection insulating material.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet, and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Ratio of Weight of Steel Section per Linear Foot and Heated Perimeter (W/D)	6.10	lb/ft^2	
Thickness of Spray-Applied Protection on Steel Beam (h) **h = 1/16 in**	3.00	in	0.250 ft
Density of Spray-Applied Material (ρ_i)	35.00	lb/ft^3	
Thermal Conductivity of Spray-Applied Material (k_i)	0.06936	Btu/ft-hr-°F	1.92667E-05 Btu/ft-sec-°F
Specific Heat of Spray-Applied Material (c_i)	0.2868	Btu/lb-°F	
Ambient Air Temperature (T_a)	77	°F	
Specific Heat of Steel (c_s)	0.132	Btu/lb-°F	

SECTIONAL FACTORS FOR STEEL BEAMS

Select Beam

6x12

Scroll to desired beam size then Click on selection

THERMAL PROPERTIES OF SPRAY-APPLIED INSULATION MATERIALS

Insulation Material Spray-Applied	Density ?$_i$ (lb/ft^3)	Thermal Cond. k_i (Btu/ft-hr-°F)	Specific Heat c_i (Btu/lb-°F)
Sprayed mineral fiber	19	0.06936	0.2868
Perlite or vermiculite	22	0.06936	0.2868
High density perlite or vermiculite	35	0.06936	0.2868

Reference: Buchanan, A. H., Structural Design for Fire Safety, 2001, (Page. 182).

Select Insulation Type

High density perlite or vermiculite

Scroll to desired material then Click on selection

ESTIMATING FIRE RESISTANCE TIME USING QUASI-STEADY-STATE APPROACH

Reference: "Analytical Methods for Determining Fire Resistance of Steel Members," SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, page 4-187.

c_s W/D > 2 c_i ρ_i h

Where c_s = specific heat of steel (Btu/lb-°F)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
ρ_i = density of spray-applied material (lb/ft^3)
c_i = specific heat of spray-applied material (BTU/lb-°F)
h = thickness of spray-applied protection on steel beam (in)

0.81 > 0

Temperature Rise in Steel Beam

$\Delta T_s = (k_i/(c_s\ h\ W/D))\ (T_f - T_s)\ \Delta t$

Where ΔT_s = temperature rise in steel (°F)
k_i = thermal conductivity of spray-applied material (Btu/ft-sec-°F)
c_s = specific heat of steel (Btu/lb-°F)
h = thickness of spray-applied protection on steel beam (in)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
T_f = fire exposure temperature (°F)
T_s = steel temperature (°F)
Δt = time step (sec)

The Maximum Allowable Time Step

Δt = 15.9 W/D
Δt = 97 sec
Δt = 1.62 minutes

For ASTM-E-119 exposure, T_f at any time, t, is given by the following expression

$T_f = C_1\ LOG\ (0.133\ t + 1) + T_a$

Where T_f = fire exposure temperature (°F)

C_1 = constant = 620
t = time step (sec)
T_a = ambient air temperature (°F)

$\Delta T_{s1} = (k_i/c_s\ h\ W/D)\ ((C_1\ LOG(0.133\ t_1 + 1) + T_a) - T_{s0})\ \Delta t$

Where $t_1 = \Delta t/2$
T_{s0} = initial steel temperature (°F)

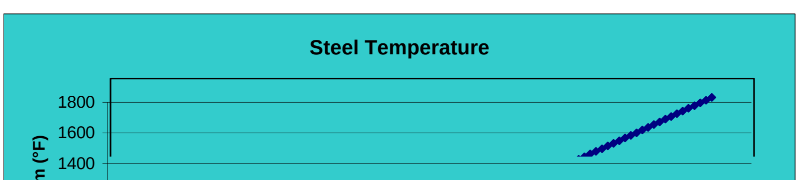
$\Delta T_{s2} = (k_i/c_s\ h\ W/D)\ ((C_1\ LOG(0.133\ t_2 + 1) + T_a) - T_s)\ \Delta t$

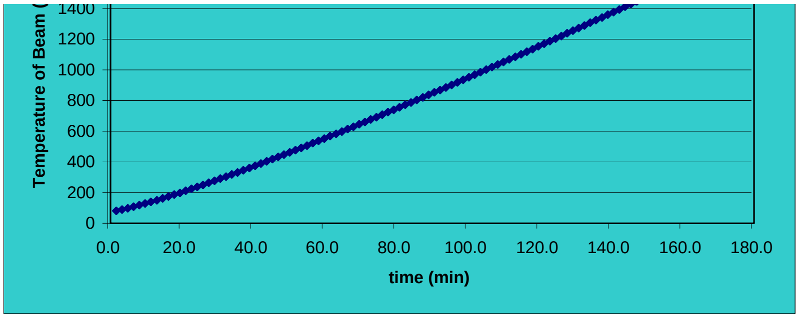
Where $t_2 = t_1 + \Delta t/2$
$T_s = T_{s0} + \Delta T_s$ from previous row

Results:

Time (min)	Time (sec)	DT_s (°F)	T_s (°F)
1.6	97	5	82
3.2	194	7	90
4.9	291	9	98
6.5	388	9	108
8.1	485	10	118
9.7	582	11	128
11.3	679	11	139
12.9	776	11	151
14.6	873	12	162
16.2	970	12	174
17.8	1067	12	187
19.4	1164	12	199
21.0	1261	13	212
22.6	1358	13	224
24.3	1455	13	237
25.9	1552	13	250
27.5	1649	13	264
29.1	1746	13	277
30.7	1843	14	291
32.3	1940	14	304
34.0	2037	14	318
35.6	2134	14	332
37.2	2231	14	346
38.8	2328	14	360
40.4	2425	14	375
42.0	2522	14	389
43.7	2619	14	403
45.3	2716	15	418
46.9	2813	15	433
48.5	2911	15	447
50.1	3008	15	462
51.7	3105	15	477
53.4	3202	15	492
55.0	3299	15	507
56.6	3396	15	522
58.2	3493	15	537
59.8	3590	15	553
61.4	3687	15	568
63.1	3784	15	583
64.7	3881	15	599
66.3	3978	16	614
67.9	4075	16	630
69.5	4172	16	645
71.1	4269	16	661
72.8	4366	16	677
74.4	4463	16	693
76.0	4560	16	709
77.6	4657	16	724
79.2	4754	16	740
80.8	4851	16	756
82.5	4948	16	772
84.1	5045	16	789

Time (min)	Time (sec)	DT_s (°F)	T_s (°F)	
85.7	5142	16	805	
87.3	5239	16	821	
88.9	5336	16	837	
90.5	5433	16	853	
92.2	5530	16	870	
93.8	5627	16	886	
95.4	5724	16	903	
97.0	5821	16	919	
98.6	5918	16	935	
100.3	6015	17	952	
101.9	6112	17	969	
103.5	6209	17	985	
105.1	6306	17	1002	failure of beam
106.7	6403	17	1019	failure of beam
108.3	6500	17	1035	failure of beam
110.0	6597	17	1052	failure of beam
111.6	6694	17	1069	failure of beam
113.2	6791	17	1086	failure of beam
114.8	6888	17	1103	failure of beam
116.4	6985	17	1119	failure of beam
118.0	7082	17	1136	failure of beam
119.7	7179	17	1153	failure of beam
121.3	7276	17	1170	failure of beam
122.9	7373	17	1187	failure of beam
124.5	7470	17	1205	failure of beam
126.1	7567	17	1222	failure of beam
127.7	7664	17	1239	failure of beam
129.4	7761	17	1256	failure of beam
131.0	7858	17	1273	failure of beam
132.6	7955	17	1290	failure of beam
134.2	8052	17	1308	failure of beam
135.8	8149	17	1325	failure of beam
137.4	8246	17	1342	failure of beam
139.1	8343	17	1360	failure of beam
140.7	8440	17	1377	failure of beam
142.3	8537	17	1394	failure of beam
143.9	8635	17	1412	failure of beam
145.5	8732	17	1429	failure of beam
147.1	8829	17	1447	failure of beam
148.8	8926	18	1464	failure of beam
150.4	9023	18	1482	failure of beam
152.0	9120	18	1499	failure of beam
153.6	9217	18	1517	failure of beam
155.2	9314	18	1535	failure of beam
156.8	9411	18	1552	failure of beam
158.5	9508	18	1570	failure of beam
160.1	9605	18	1588	failure of beam
161.7	9702	18	1605	failure of beam
163.3	9799	18	1623	failure of beam
164.9	9896	18	1641	failure of beam
166.5	9993	18	1659	failure of beam
168.2	10090	18	1677	failure of beam





The Failure Temperature for Steel Beams is 1000 °F

NOTE

The above calculations are based on principles developed in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 2nd Edition 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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CHAPTER 17 - METHOD OF ESTIMATING THICKNESS OF FIRE PROTECTION SPRAY-APPLIED COATING FOR STRUCTURAL STEEL BEAMS (SUBSTITUTION CORRELATION)

For beams protected by spray-applied protections, following correlation enables substitution of one beam from another by varying the thickness of the fire protection insulation.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet, and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Rated Design Thickness of Beam Insulation (T_2) 2.5 in

Known Insulation Rating

Weight of the Beam (W_2) 12 lb/ft
Heated Perimeter of Beam (D_2) 23.6 in

Unknown Insulation Rating

Weight of the Beam (W_1) 20.00 lb/ft
Heated Perimeter of Beam (D_1) 29.94 in

SECTIONAL FACTORS FOR STEEL BEAMS

Select the Beam with **known** rating for insulation thickness	Select the Beam with **unknown** rating for insulation thickness
W6 x 12	W6 x 20
Subscript 2 **(Rated Beam)**	**Subscript 1** **(Substitute Beam)**

ESTIMATING THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

Reference: UL Fire Resistance Directory, Volume 1, 1995 (Page 19).

$T_1 = ((W_2/D_2 + 0.6)T_2)/(W1/D_1 + 0.6)$

Where T_1 = calculated thickness of fire protection insulation on unrated beam (in)
T_2 = design thickness of insulation on rated beam (in)
W_1 = weight of beam with unknown insulation rating (lb/ft)
W_2 = weight of design rated beam (lb/ft)
D_1 = heated perimeter of unrated beam (in)
D_2 = heated perimeter of the rated beam (in)

Required Equivalent Thickness of Fire Protection Insulation on Unrated Beam

$T_1 = ((W_2/D_2 + 0.6)T_2)/(W1/D1 + 0.6)$

T_1 = 2.19 in **ANSWER**

Beams with a larger W/D ratio can always be substituted for the structural member listed with a specific fire resistive covering without changing the thickness of the covering.

NOTE

The above calculations are based on method developed in the UL Fire Resistance Directory, Volume 1, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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Office of Nuclear Reactor Regulation
Division of Systems Safety and Analysis
Plant Systems Branch
Fire Protection Engineering and Special Projects Section

CHAPTER 18 - METHOD OF ESTIMATING VISIBILITY THROUGH SMOKE

The following calculations estimate the smoke obscuration during a fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the guide should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	20.00	ft
Compartment Height (h_c)	10.00	ft
Mass of Fuel Burn (M_f)	0.50	lb
Particulates Yield (y_p)	0.1180	
Proportionality Constant for Visibility (K)	3	
Mode of Combustion (α_m)	37000	ft^2/lb

PARTICULATE YIELD FOR WELL-VENTILATED FIRES OF SOLID FUELS

Materials	Particulate Yield y_p
Wood (Red Oak)	0.015
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Fiberboard	0.008
Wool 100%	0.008
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Silicone	0.065
Polyester	0.09
Nylon	0.075
Silicone Rubber	0.078
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polystyrene Foam	0.194
Polyethylene Foam	0.076
Phenolic Foam	0.002
Polyethylene (PE)	0.06
Polyvinylchloride (PVC)	0.172
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Perfluoroalkoxy (PFA; Teflon™)	0.002
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Tetrafluoroethylene (TFE; Teflon™)	0.003

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 35.

Select Material
Polyurethane Foam (Rigid)
Scroll to desired material then Click on selectio

RECOMMENDED PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Illuminated Signs	8
Reflecting Signs	3
Building Components in Reflected Light	3

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 31.

Select Proportionality Constant (K)
Reflecting Signs
Scroll to desired situation then Click on selectic

SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Smoldering Combustion	21000
Flaming Combustion	37000

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 32.

Select Specific Extinction Coefficient (α_m)
Flaming Combustion
Scroll to desired combustion mode then Click o

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 32.

$S = K / \alpha_m m_p$

Where S = visibility through smoke (ft)
K = proportionality constant
α_m = specific extinction coefficient (ft^2/lb)
m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$V = w_c \times l_c \times h_c$

Where V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

$V =$ **4000.00** ft^3

Mass of Particulates Produced (airborne particulate)

$M_p = y_p M_f$

Where M_p = mass of particulates produced (lb)
y_p = particulates yield
M_f = mass of fuel consumed (lb)

$M_p = y_p M_f$

$M_p =$ **0.059** lb

Mass Concentration of the Particulates Calculation

$m_p = M_p / V$

Where m_p = mass concentration of the particulates (lb/ft^3)
M_p = mass of particulates produced (lb)
V = volume of the compartment (m^3)

$m_p = M_p / V$

$m_p =$ **0.00001475** lb/ft^3

Visibility Through Smoke Calculation

$S = K / \alpha_m m_p$

S = 5.50 ft **ANSWER**

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
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